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ON VENUS MODEL WITH "COLD" ABSORBING ATMOSPHERE

by
A. D. Kuz'min
[USSR]

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ON VENUS MODEL WITH "COLD" ABSORBING ATMOSPHERE

Izv.Vysshikh Uch.Zavedeniy,
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by A. D. Kuz'min

SUMMARY

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The possibility is considered of interpreting the observed Venus' radio emission spectrum in centimeter and millimeter bands by wave absorption in the atmosphere aerosol of the planet. It is shown that the steep slope in the millimeter band of the spectrum may be explained by absorption in trickle-liquid aerosol at temperature of $\sim 300^{\circ}$ K and containing $0.2 - 0.3$ g cm^{-2} of polar liquid with $3.5 \cdot 10^{-12}$ sec. relaxation time. Such liquids can be constituted by some functional derivatives of methane CH_4, ethane C_2H_6, benzol C_6H_6 and others. Dust aerosol, consisting of rocks and volcanic formations, does not satisfy the experimental data.

It is shown, that the atmosphere model, yielding to the observed radiospectrum, must be entirely nontransparent in the infrared and optical bands. Therefore, the surface heating of the planet cannot be the result of direct solar radiation.

The surface heating by planet's inner heat is also considered and the necessary heat flow is estimated.

The possibility of explaining the measured Venus' brightness temperature decrease in decimeter band by wave absorption in relatively

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* O MODELI VENERY S "KHOLODNOY" POGLOSHCHAYUSHCHEY ATMOSFEROY.

cold Venus ionosphere ($\sim 300^{\circ}$ K) is indicated. The required electron concentration of the ionosphere with holes, and the collision frequency of a semi-transparent ionosphere are estimated.

* * *

Author

1.- As is well known, the strong absorption of shortwaves in the relatively cold atmosphere of the planet can be one of the possible causes of lower brightness temperature of Venus' radio emission in millimeter band by comparison with longer waves [1]. However, the question of nature of the absorbing agent is still in the dark.

Nephelometric [2] and polarization [3] measurements of Venus in the optical band point to great aerosol content in its atmosphere. In terrestrial conditions, the atmosphere aerosol (clouds, fog) is absorbing for radio emission in the shortwave part of the centimeter and millimeter bands (see for example [4]). It is possible, that Venus' cloud layer is also aerosol-constituted. In connection with this it appears to be interesting to consider the possible explanation of the observed spectrum of Venus' radio emission by selective absorption properties of aerosol particles.

2.- We shall seek the solution of the problem of ascertaining the electrical properties of the absorbing layer from the experimental data on the radio emission spectrum of Venus.

The planet's brightness temperature is determined by the transfer equation solution, since the planet is surrounded by the absorbing layer. Assuming in the first approximation such a layer as plane, we shall have

$$T_{\text{a}}(\lambda) = T_{\text{п}}(1-R)\,e^{-\int_{h_1}^{h_2}\gamma(\lambda,s)\,ds} + \int_{h_1}^{h_2} T_{\text{c}}(s)\,\gamma(\lambda, s)\,e^{-\int_{s}^{h_2}\gamma(\lambda, s)\,ds}\,ds. \qquad (1)$$

Here $T_{\text{п}}$ and R are the temperature and the reflection factor of the surface, s is the current coordinate, h_1 and h_2 are the heights of the lower and upper boundaries of the layer, $T_{\text{c}}(s)$ and $\gamma(\lambda, s)$ are the distribution of temperature and absorption in the layer in height.

Assume that an exponential absorption decrease takes place in the layer as a function of height :

$$\gamma(\lambda, s) = \gamma_0(\lambda)\, e^{-(s-h_1)/H}, \tag{2}$$

where $\gamma_0(\lambda)$ is the absorption at layer's lower boundary, H is the height of the uniform layer. We shall assume the distribution of temperature on the layer as linear :

$$T_c(s) = T_1 - (T_1 - T_2)\frac{s-h_1}{h_2-h_1}, \tag{3}$$

where T_1 and T_2 are the temperatures at lower and upper boundaries of the layer. Denoting $\gamma_0(\lambda) H = B(\lambda)$ and $e^{(h_2-h_1)/H} = A$ and effecting a series of transformations, we shall obtain

$$T_2(\lambda) = T_2 + |T_\pi(1-R) - T_1|\, e^{-B(1-A)} + \\ + \frac{T_2 - T_1}{\ln A}\,[E_i(-B) - E_i(-AB)]. \tag{4}$$

Here E_i is an integral exponential function.

Assuming $T_\pi(1-R) = 580^\circ$ K and $T_2 = 250^\circ$ K, we shall find the dependence $T_B[B(\lambda)]$ for various values of T_1, $(h_2 - h_1)/H$ and H, given as parameters. The results of computations are represented in the form of a graph in Fig. 1.

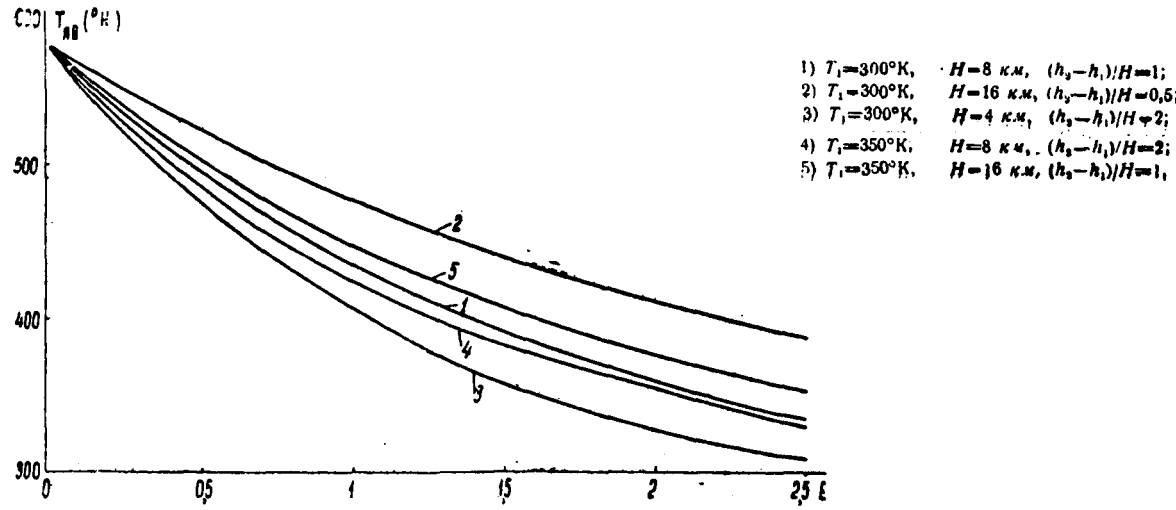

Fig. 1. - Brightness temperature of Venus $T_{яB}$ as a function of atmosphere optical thickness $B = \gamma_0 H$.

Plotted in Fig. 2 are the currently well known data on spectral measurements of Venus' brightness temperature (dark side) [5 — 10].

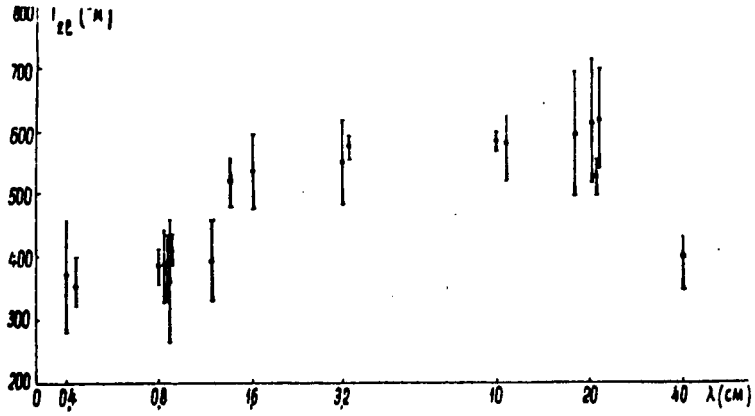

Fig. 2. - Radio emission spectrum of the dark side of VENUS.

With the help of the graph Fig. 1, it is possible to determine for every point of Fig. 2 the absorption $B(\lambda)$, for which the calculated temperature of the model under consideration corresponds to the measured value. The results of such a calculation for $T_1 = 300^\circ K$, $H = 8$ km and $(h_2 - h_1)/H = 1$. are plotted in Fig. 3. The values of errors in this figure correspond to errors of T_{RB} measurements, plotted in Fig. 2. It is obvious from Fig. 3 that it is possible to satisfy the observed spectrum of Venus radio emission at the condition that the absorption in the atmosphere be small at wavelengths greater than 3 cm, and rise sharply in the 1.5 to 1 cm wavelength range.

The weakening of the electromagnetic radiation by aerosol particles small by comparison with the wavelength, is determined by the correlation [4]:

$$\gamma(\lambda) = 56{,}5\,\frac{C_1(\lambda)\,M}{\lambda}\,cM^{-1}, \qquad (5)$$

$$C_1(\lambda) = \frac{\varepsilon''(\lambda)}{[\varepsilon'(\lambda)+2]^2 + \varepsilon''(\lambda)^2},$$

where M is the mass of absorbing particles, ε' and ε'' are the real and imaginary parts of the complex dielectric constant of particle matter.

It is not difficult to show, that in order to obtain the spectral dependence of the absorption plotted in Fig. 3, the values of ε' and ε'' of aerosol matter must vary sharply in the shortwave part of the centimeter band.

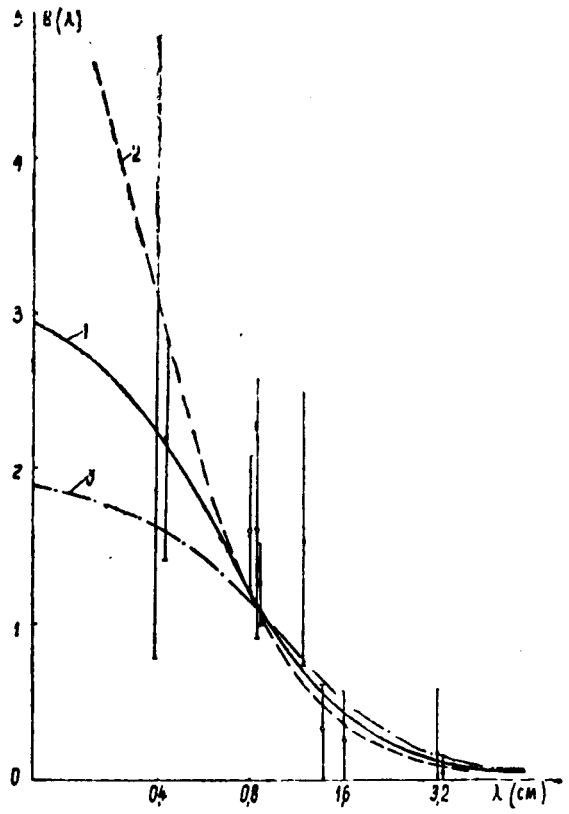

Fig. 3. - Dependence of atmosphere optical thickness B on the wavelength λ: vertical segments represent the values $B(\lambda)$ required for obtaining $T_{\text{я}B}$, indicated in Fig. 2.; the solid line is the computed value for $B(0) = 3$, ———— $\tau_p = 3{,}5 \cdot 10^{-12}$ sec., —— the dashed line for ———— $B(0) = 6{,}5$, $\tau_p = 2 \cdot 10^{-12}$ sec ———— and the dash-dotted line for ———— $B(0) = 2$, $\tau_p = 5 \cdot 10^{-12}$ sec.

According to [11], ε' and ε'' of rocks and volcanic formations or ashes do not depend on wavelength in the band of interest to us. That is why it is not possible to explain the observed spectrum of Venus' radio emission by selective absorption in the dust aerosol consisting of above-indicated formations.

On the other hand, polar liquids of little viscosity, for which the frequency dependences $\varepsilon'(\lambda)$ and $\varepsilon''(\lambda)$ are described by the correlations

$$\varepsilon'(\lambda) = \varepsilon_\infty + \frac{\varepsilon_0 - \varepsilon_\infty}{1+y^2}, \qquad \varepsilon''(\lambda) = \frac{(\varepsilon_0 - \varepsilon_\infty)\, y}{1+y^2}, \tag{6}$$

where

$$y = \omega\tau_p \frac{\varepsilon_0 + 2}{\varepsilon_\infty + 2}, \tag{7}$$

τ_p is the relaxation time of polar molecules, ε_0 and ε_∞ are the dielectric constants of the matter in the frequencies $\omega_0 \ll 1/\tau_p$ $\omega_\infty \gg 1/\tau_p$. Substituting (6) into (5), we shall obtain the calculated dependence $\gamma(\omega\tau_p)$ and, consequently, $B(\omega\tau_p)$. The results of computations are plotted in Fig. 4; they make evident the noncriticalness of the shape of the curve $\gamma(\omega\tau_p)$ relative to parameters ε_0 and ε_∞. The position of the "cut"

corresponds to frequencies $\omega \simeq 1/\tau_p$. The value of $B(\omega\tau_p)$ $(\tau_p 10^{12}/M_0H)$. is plotted in ordinates.

Comparison of experimental data with the computed ones for various parameters τ_p and $B(0) = B_{\lambda\to 0}(\omega\tau_p)$. A good agreement of the experiment with the calculation takes place at $\tau_p = 3.5 \cdot 10^{-12}$ sec and $B(0) = 3$. The parameter B (0) exerts a strong influence upon the value of brightness temperature in the wave band $\lambda < 4$ mm and can be made more precise after conducting the respective measurements.

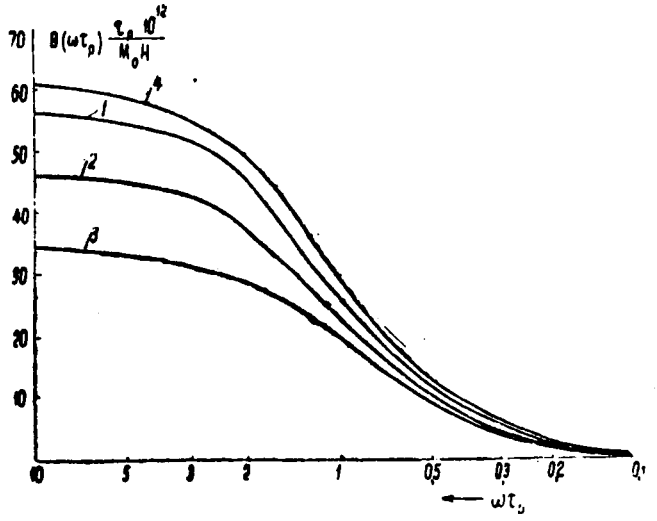

Fig. 4. - Computed dependence of the optical thickness B of the polar aerosol on frequency ω and relexation time τ_p: 1) $\varepsilon_0=81$, $\varepsilon_\infty=3$; 2) $\varepsilon_0=20$, $\varepsilon_\infty=3$; 3) $\varepsilon_0=10$, $\varepsilon_\infty=3$; 4) $\varepsilon_0=20$, $\varepsilon_\infty=2$.

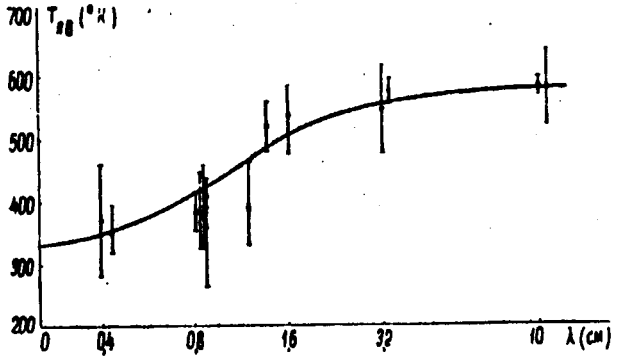

Fig. 5. - Computed spectrum of Venus, surrounded by "cold" aerosol containing 0.2 — 0.3 g·cm^{-2} of polar liquid with relaxation time τ_p $3.5 \cdot 10^{-12}$ sec.

Let us conduct the estimate of the necessary amount of absorbing matter. Passing to limit in (5) at $\lambda \to 0$, we shall have

$$B(0) = \gamma_0(0)H = \frac{3\cdot 10^{-10} M_0 H}{\tau_p} \frac{\varepsilon_0 - \varepsilon_\infty}{(\varepsilon_0+2)(\varepsilon_\infty+2)},$$

and hence

$$M_0 H = \frac{B(0)\tau_p}{3\cdot 10^{-10}} \frac{(\varepsilon_0+2)(\varepsilon_\infty+2)}{\varepsilon_0-\varepsilon_\infty}.$$

Here M_0 is the quantity of absorbing matter in 1 cm^3 of atmosphere of Venus at level h_1. Assuming, in accordance with the above-expounded,

$B(0) = 3$ and $\tau_p = 3.5 \cdot 10^{-12}$ sec, and assigning ourselves various values for ε_0 from 81 to 10 and $\varepsilon_\infty = 3 \pm 2$, we shall obtain $M_0 H = 0.2 \pm 0.3$ g of absorbing matter in a 1 cm^2 column of the layer. Assuming the height of the uniform layer equal that of uniform atmosphere on Earth $H \simeq 8$ km, we shall estimate the concentration of absorbing matter in 1 cm^3 of the atmosphere of Venus : $M_0 = 0.25 \pm 0.38$ $g \cdot m^{-3}$.

The computed spectrum of Venus' radio emission, whose atmosphere contains the indicated amount of trickle-liquid aerosol, is plotted in Fig. 5 coinciding with the results of measurements with a precision to measurement errors. Thus, the steep slope in the millimiter part of the spectrum of Venus' radio emission can be explained by absorption in trickle-liquid aerosol of the planet, at a temperature $\sim 300^\circ$ K and containing 0.2 ± 0.3 g cm^{-2} of polar liquid with a relaxation time of $\tau_p = 3.5 \cdot 10^{-12}$ sec.

Although water is a polar liquid, it apparently fails to explain the observed spectrum, for its relaxation time $\tau_p = (0.5 \cdot 10^{-12}$ sec. at $t = 15^\circ$ C) is nearly by one order smaller than that required. Certain functional derivatives of methane, ethane and benzol, for example, CH_3OH, $(C_2H_5)_2O$, C_6H_5Cl, C_6H_5Br and others have a relaxation time near that required.

Fig. 3 shows, that the required absorption exceeds the computed one in 8 mm and 1.18 cm wavelength, which satisfies the remaining experimental points. This provides a basis to assume, that the agreement between the computed spectrum and the experimental data of Fig. 3 can be improved in the presence, in the indicated wavelengths, of additional absorption. However, the spectrum of the complementary absorption must not have notable components in the 1.35, 1.6 and 3 cm wavelengths, where the complementary absorption would rather deteriorate the agreement between calculation and experiment. Such relative narrowbandness can assure absorption in gases having strong lines in wavelengths between 4 mm and 1.35 cm (CH_3OH, CH_3CN, C_2H_4O, ClCN, BH_3CO, FCl, and HCF_3[21]). A particular interest is offered by CH_3OH, for the liquid phase of this substance satisfies the requirement aerosol composition of the planet.

3. - Let us estimate the transparency of the layer in the infrared. According to polarimetric measurements by Lyot [3], the diameter of aerosol particles is $d \simeq 2.5\,\mu$, thus commensurate with the wavelength of the infrared radiation. In this case the effective cross section of radiation's weakening is [13]

$$\sigma \simeq \pi r^2, \tag{9}$$

where r is the radius of particles. The layer's optical thickness is

$$\tau = \sigma N, \tag{10}$$

where the number of drops in a column of $1\,cm^2$ cross section is

$$N = 3M_0H/4\rho\pi r^3. \tag{11}$$

Substituting (9) and (11) into (10), and assuming the density of the absorbing matter $\rho \simeq 1$, , we shall obtain

$$\tau = 3M_0H/4\rho r = 1200 \div 1800,$$

i. e., this aerosol must be entirely nontransparent for the infrared radiation (and such atmosphere will be obviously nontransparent even in visible light). This corresponds to experimental data of [14], which point to the fact that the atmsophere of Venus, observed from without, becomes optically thick already at cloud layer summit level. In this case the solar radiation must be fully retained by the upper part of the cloud layer, whose temperature will be determined by radial equilibrium conditions. The temperature of $\sim 240^\circ$ K, obtained for the upper part of the cloud layer in [15] by radiometric observations, is indeed close to the equilibrium radiation temperature.

From the atmosphere's nontransparency it follows also, that the direct solar radiation cannot be the source of heating Venus' surface. In this case the surface temperature of the lit and unlit sides must be identical. However, the available phase course of Venus' radio emission brightness temperature can be explained by the effect of solar radiation upon the optical thickness $B = \gamma_0 H$ of the "cold" absorbing atmosphere. The decrease in amplitude of the phase course with wavelength, expected in this case, corresponds apparently to experimental data of [1, 6, 22, 17].

Incidently, let us note, that if the phase course is conditioned by surface temperature variation, one should expect an increase in the

amplitude of the phase course with the wavelength; this, however, is not confirmed by the experimental data. Therefore, the character of the phase course dependence on the wavelength can be helpful in the solution of the question, as to whether or not, the phase course is conditioned by surface temperature variation, or else, its cause would be residing in the variation of absorption in the "cold" atmosphere of the planet.

If the source of Venus'surface heating is the Sun, a certain other energy tranfer mechanism would be required between the upper part of the cloud layer and the surface of the planet. One of such mechanisms (heating by wind friction) is considered by Öpik in an aeolospheric model [18].

4. The planet's inner heat could constitute still another source of heating. Let us consider such a possibility and estimate the magnitude of inner heat flow required to that effect.

As is well known, the planet's temperature regime is determined by sources' and heat losses' balance. The losses of heat from planet surface to outer space accrue in the general case from losses to radiation, to atmosphere heat conductivity and to turbulent heat transfer. Let us estimate these losses.

The losses to heat conductivity in a gas are determined by the correlation

$$q_{heat} = \lambda \Delta T, \qquad (12)$$

where λ is the coefficient of heat conduction, ΔT is the temperature gradient in the heat transfer direction. Taking the coefficient of atmosphere heat conduction equal that of the terrestrial atmosphere

$$\lambda \simeq 7.5 \cdot 10^{-5} \text{ cal cm}^{-1} \text{ sec}^{-1} \text{ deg}^{-1},$$

and the temperature's vertical gradient equal to the adiabatic one for the dry air

$$\Delta T = \gamma_a \simeq 10^{-4} \text{ deg} \cdot \text{cm}^{-1},$$

we obtain

$$q_{heat} \simeq 10^{-8} \text{ cal} \cdot \text{cm}^{-2} \cdot \text{sec}^{-1}$$

As may be seen, losses to heat conductivity are by 2.5 orders less than the inner heat flow at the Earth, and, consequently, at the same inner heat flux at Venus they should not practically influence the thermal regime of the planet.

Considerably greater might be the turbulent heat losses. According to [19], the turbulent heat flow q_{turb} is proportional to the difference between the true, ΔT, and the equilibrium, β temperature gradients:

$$q_{turb} = \lambda^* (\Delta T - \beta). \qquad (13)$$

Assuming for the sake of estimation, that the coefficient of turbulent heat conduction corresponds to the parameter for the terrestrial atmosphere [19], that is $\lambda^* \simeq 10^3$ cal$\cdot$cm^{-1}min^{-1} deg^{-1} and $\Delta T - \beta \simeq 10^{-6}$ deg$\cdot$cm^{-1}, we shall obtain

$$q_{turb} \simeq 1.6 \cdot 10^{-4} \text{ cal cm}^{-2} \cdot \text{sec}^{-1}.$$

Therefore, in the adopted model the heat losses by the surface are

$$q_{\Sigma} = q_{rad} + q_{heat} + q_{turb} \qquad (14)$$

and they are determined mainly by turbulent losses. Consequently, an inner heat source is necessary for the heat balance, that would ensure an inflow

$$q = q_{\Sigma} \simeq 1.6 \cdot 10^{-4} \text{ cal}\cdot\text{cm}^{-2}\cdot\text{sec}^{-1},$$

that is by 2 orders greater than the inner heat flow available on Earth. If the inner heat source is the planet's radioactivity, the radioactive matter content on Venus must also be by 2 orders greater than on Earth.

Because of rough estimate of turbulent heat transfer, the above-expounded data must be considered as preliminary and requiring further improvement.

5.- The latest measurements by Drake [6], carried out in the 21 and 40 cm wavelengths (Fig. 2), point to Venus' brightness temperature decrease in the decimeter band. We shall attempt to interpret the indicated decrease in a "hole-filled" or semitransparent ionosphere of Venus.

As is shown in [20], the brightness radio emission temperature of the planet, surrounded by such an ionosphere, is

$$T_я(\lambda) = T_п\ (1-R) + b\,[T_e - T_п\ (1-R)]\,(1-e^{-\tau(\lambda)}), \quad (15)$$

where T_e is the kinetic temperature of electrons in the ionosphere, τ is the optical thickness of the ionosphere, b is the ratio of the ionosphere-covered planet disk area to the total one.

Assume that the ionosphere of Venus is transparent in the centimeter band and absorbing at greater wavelengths. In this case, in order to decrease the brightness temperature in the decimeter band, it is necessary that the kinetic temperature of electrons in the ionosphere T_e be lower than the brightness temperature of the surface $T\ (1-R)$. In Fig. 6 we plotted the computed spectra of Venus' radio emission with a "hole" ionosphere, constructed for $T_п\ (1-R) = 580^\circ$ K and $b\,[T_e - T_n\ (1-R)]$ and zN_γ, equal to -200° K, $6 \cdot 10^{20}$ cm^{-2} sec^{-1} and -300° K, $2 \cdot 10^{20}$ cm^{-2} sec^{-1} respectively. Comparison with the experimental points, plotted in the same figure, is evidence of their agreement.

If the absorbing layer is situated in planet's upper atmosphere, the collision frequency is determined by collisions with ions:

$$\nu_{ei} = 6.1\ \ 10^{-3} \sqrt{\ (300/T_e)^3\ }\ N_i.$$

Assuming $T_e \simeq 300^\circ$ K, and a layer thickness of 50 km ($z = 50$ km), we shall estimate the required electron concentration in the layer:

$$N = (1 \div 2) \cdot 10^8 \text{ cm}^{-3}.$$

The collision frequency in the lower atmosphere layers is determined by collisions with neutral particles:

$$\nu_{en} = 3{,}6 \cdot 10^{-10}\, n \sqrt{T_e}.$$

Assuming $T_e \simeq 300^\circ$ K and $n \simeq 3 \cdot 10^{18}$ cm^{-3}, we shall obtain $\nu_{en} = 2 \cdot 10^{10}$ sec^{-1}. For a layer thickness $z = 10$ km, this corresponds to an electron concentration in the layer

$$N = (1 \div 3) \cdot 10^4 \text{ cm}^{-3}.$$

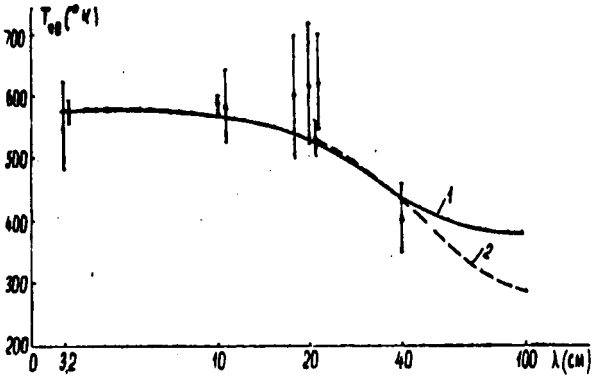

Fig. 6.- Computed spectrum of decimeter radio emission of Venus, surrounded by a "cold" hole ionosphere :

curve 1 — for $b[T_e - T_n(1-R)] = -200°K$, $zN\nu = 6 \cdot 10^{20}\ см^{-2} \cdot sec^{-1}$,

curve 2 — for $b[T_e - T_n(1-R)] = -300°K$, $zN\nu = 2 \cdot 10^{20}\ см^{-2} \cdot sec^{-1}$.

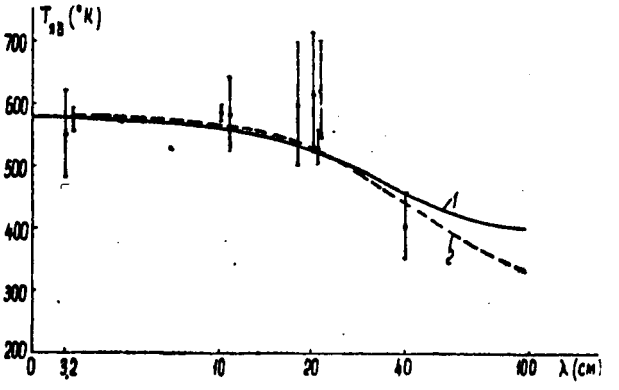

Fig. 7.- Computed spectrum of decimeter radio emission of Venus, surrounded by a "cold" semitransparent ionosphere :

curve 1 — for $[T_e - T_n(1-R)][1 - e^{-\tau_{\omega \to 0}}] = -200°K$, $\nu = 5 \cdot 10^9\ sec^{-1}$

curve 2 — for $[T_e - T_n(1-R)][1 - e^{-\tau_{\omega \to 0}}] = -30°K$, $\nu = 3 \cdot 10^9\ sec^{-1}$

In case of semitransparent ionosphere, a collision frequency

$$\nu = (3 \div 5) \cdot 10^9\ sec^{-1}$$

is required for the agreement with experimental data. It can only be attained in the lower dense layers of the planet's atmosphere. The computed spectrum of Venus' radio emission with a semitransparent ionosphere is plotted in Fig. 7. It also agrees well with the experiment.

For a further precision in the determination of ionosphere parameters, measurements of Venus' brightness temperature in wavelengths greater than 40 cm are required.

* * * *

CONCLUSIONS

1. - The measured decrease of Venus' brightness temperature in the microwave part of planet's radio emission spectrum can be explained by absorption in trickle-liquid atmospheric aerosol of Venus, at a temperature of $\sim 300^{\circ}$ K and containing $0.2 \div 0.3$ g cm^{-2} of polar liquid with $\sim 3.5 \cdot 10^{-12}$ sec. relaxation time.

2. - Certain functional derivatives of methane, ethane or benzol, for example, CH_3OH, $(C_2H_5)_2O$, C_6H_5Cl, could be such liquids.

3. - The dust aerosol, consisting of rocks or volcanic formations, does not satisfy the observed spectrum.

4. - The atmosphere, containing trickle-liquid aerosol and satisfying the observed radiospectrum, is entirely nontransparent for both, the infrared and the visible radiations. That is why the direct solar radiation cannot be the source of planet surface heating.

5. - The decrease of Venus' brightness temperature, measured by Drake in the decimeter band, may be explained by absorption ina hole and semitransparent ionosphere of Venus, having an electron temperature of $\sim 300 \div 400^{\circ}$ K.

***** THE END *****

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	STONE	
640	HESS	[3]
	O'KEEFE	
641	LOWMAN	
	MAEDA	
	HARRIS	
660	GI for SS	[5]
252	LIBRARY	[3]
256	FREAS	

NASA HQS

SS	NEWELL, CLARK	
SG	NAUGLE	
	SCHARDT	
	ROMAN	
	SMITH	
	DUBIN	
SL	LIDDEL	
	BRUNK	
	FELLOWS	
	HIPSHER	
	HOROWITZ	
SM	BADGLEY	
	FOSTER	
	ALLENBY	
	GILL	
RR	KURZWEG	
RTR	NEILL	
ATSS	SCHWIND	[5]
WX	SWEET	

OTHER CENTERS.

AMES R.C.

SONETT [5]
LIBRARY [3]

LANGLEY

160 ADAMSON
235 SEATON
BABCOCK III
213 KATZOFF
185 WEATHERWAX [3]

JPL

NEWBURN
SPEED
CONEL
KOVACH
LOOMIS

UCLA

COLEMAN

UC BERKELEY

WILCOX

N.O.

Lib.